TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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WIND-TUNNEL INVESTIGATION OF RECTANGULAR AND TAPERED N.A.C.A. 23012 WINGS WITH PLAIN AILERONS AND FULL-SPAN SPLIT FLAPS

By Carl J. Wenzinger and Milton B. Ames, Jr.
Langley Memorial Aeronautical Laboratory

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SUMMARY

An investigation was made in the N.A.C.A. 7- by 10-foot wind tunnel to determine the aerodynamic properties of rectangular and tapered N.A.C.A. 23012 wings with plain ailerons and a full-span split flap, the flap retracting ahead of the ailerons. Measurements were made of lift and drag and of pitching, rolling, yawing, and hinge moments for all conditions of full-span flaps neutral and deflected at different chord locations.

The results of the tests showed that a $0.20c_w$ full-span split flap located at approximately the $0.75c_w$ point gave higher lift coefficients than had previously been obtained with a conventional $0.20c_w$ partial-span split flap of a length to permit satisfactory control with plain ailerons. Still higher lifts were obtained if the full-span flap, when deflected, was moved back to the aileron axis. Moving the flap back to the aileron axis, in general, improved the aileron characteristics over those with the flap retracted. The most promising arrangement of full-span split flap and plain aileron combination tested, both for high lift and lateral control, was the rectangular wing with $0.20c_w$ flap deflected 60° at the $0.90c_w$ location with $0.10c_w$ semispan ailerons.

INTRODUCTION

The most commonly used device for increasing the maximum lift coefficient over that obtained with a conventional wing is the partial-span split flap extending along the inner portion of the wing span. For lateral control, trailing-edge ailerons that extend from the outboard ends of the flap to the wing tips are used. Naturally, such an arrangement does not take full advantage of the potential value of the flap in assisting the take-off, in decreasing the landing speed, and in steepening the gliding angle at landing.

Full-span high-lift devices are seldom used on airplanes at the present time because of the difficulty of obtaining satisfactory lateral control with the lift-increasing device extending along the entire trailing edge of the wing. A number of control devices adaptable to wings with a full-span flap have been investigated (references 1 and 2) and several of the devices showed considerable promise.

One of the devices tested consisted of a combination of plain ailerons and a full-span split flap, the flap retracting ahead of the ailerons. The brief flight investigation (reference 1) of the arrangement having shown it to be one of the most satisfactory of the devices tested, considerably more detailed aerodynamic information for the device appeared desirable.

The present investigation includes tests of a rectangular wing and of a highly tapered wing with plain ailerons of different size and with full-span split flaps of different chord tested at several locations.

APPARATUS AND TESTS

Models

Two wing models were used: one has a rectangular plan form and the other is tapered 5:1. Both models have a span of 60 inches and a geometric aspect ratio of 6. The wings are of laminated mahogany and are of N.A.C.A. 23012 profile. The maximum ordinates for all sections of the tapered wing on the upper surface are in a horizontal plane and the slopes in plan form of the leading and trailing edges are equal.

The tested arrangements are listed in the following table; the combinations are shown in figures 1 to 5.

Model Arrangements Tested

Wing plan form	Aileron size (percent c_w by percent b/2)	Flap chord (percent c_w)	Flap location (percent c_w)	Flap deflection (deg.)
Rectangular	-		15	
	-		50	
	15 by 60	20	65	60
			85	
	10 by 100		70	
			90	
		10	80	75
			90	
Tapered	15 by 60	20	65	60
			85	

The aileron sizes were chosen on the basis of those giving sufficient and approximately the same amount of rolling control under similar conditions. The ailerons on the rectangular wing were rectangular in plan form and those on the tapered model tapered with the wing, the chord at any longitudinal section being 15 percent of the wing chord (c_w) at the same point.

Earlier tests (reference 3) showed that moments caused by both right and left ailerons could be found separately and added to give the total effect. The models were therefore constructed with ailerons on only the right wing.

The ailerons were constructed so that they could rotate freely in order that the hinge-moment coefficients could be determined. Hinge moments were measured by the calibrated twist of a long slender steel rod extending along the hinge axis from the aileron through the tunnel wall to the balance frame outside the test chamber. A locking device held the aileron rigidly at a given deflection while the rolling and yawing moments were being measured. In all tests the gap between the aileron and the wing was sealed with a light grease because it has been shown (reference 4) that the rolling moments are decreased when the gap is left open.

The full-span split flaps were rectangular in plan form on the rectangular model and tapered with the wing on the tapered model, the chord at any longitudinal section being 20 percent of the wing chord at the same section. All the flaps were made of 1/16-inch sheet steel and were attached by small wood screws to the wing at the desired angle.

Wind Tunnel

The tests were made in the N.A.C.A. 7- by 10-foot tunnel, which has a closed test chamber and return passage. The tunnel and the regular 6-component balance are described in references 5 and 6. On this balance the six components of aerodynamic forces and moments are measured independently and simultaneously with respect to the wind axes of the model.

Tests

The dynamic pressure was maintained constant throughout the tests at 16.37 pounds per square foot, corresponding to an air speed of about 80 miles per hour at standard sea-level conditions. The average test Reynolds Number was 609,000 based on the mean wing chord of 10 inches. The angle-of-attack range extended from below zero lift to beyond the stall of the wing. Aileron deflections ranged from -40° (up) to 30° (down) and were measured in a plane perpendicular to their hinge axes.

Force tests were made of the rectangular and the tapered wings with the ailerons neutral and the full-span split flaps neutral and deflected at the different flap locations. The flap deflections chosen are those giving the maximum lift for each size used. With these arrangements lift, drag, and pitching-moment coefficients were measured. The ailerons were then deflected and the rolling-, the yawing-, and the hinge-moment coefficients were obtained for the conditions of flaps neutral and flaps deflected at the various locations.

RESULTS AND DISCUSSION

Form of presentation of Data

The test results are given in the form of absolute coefficients of lift and drag, and of pitching, rolling, yawing, and hinge moments.

$$C_L = \frac{\text{lift}}{qS}$$

$$C_D = \frac{\text{drag}}{qS}$$

$$C_{m_{(a.c.)_o}} = \frac{\text{pitching moment about aerodynamic center of plain wing}}{qcS}$$

$$C_l' = \frac{\text{rolling moment}}{qbS}$$

$$C_n' = \frac{\text{yawing moment}}{qbS}$$

$$C_{h_a} = \frac{\text{hinge moment}}{qc_aS_a}$$

where S is the wing area.

b, the wing span.

c, the mean geometric chord of the wing.

S_a, the area of one aileron.

c_a, the root-mean-square chord of a tapered aileron; i.e., the square root of the mean of the squares of the aileron chords along its span,

q, the dynamic pressure.

All coefficients, except those of the hinge moment, were obtained directly from the balance and refer to the wind (or tunnel) axes.

The data were corrected for tunnel effects to aspect ratio 6 in free air. The standard jet-boundary corrections were applied:

$$\Delta\alpha = \delta \frac{S}{C} C_L \, 57.3 \quad \text{(degrees)}$$

$$\Delta C_D = \delta \frac{S}{C} C_L^2$$

where C is the jet cross-sectional area. A value of $\delta = 0.117$ for the closed-throat 7- by 10-foot wind tunnel was used in correcting the test results.

Effect of Flap Location and Flap Chord on Wing Characteristics

Lift and drag coefficients for the rectangular wing with the $0.20c_w$ split flap at different locations are given in figure 6 and the pitching-moment coefficients, in figure 7. Similar data for the rectangular wing with the $0.10c_w$ split flap at different locations are given in figures 8 and 9. The lift and drag coefficients of the 5:1 tapered wing with the $0.20c_w$ tapered flap at different locations are given in figure 10 and the pitching-moment coefficients are given in figure 11. The effect of flap location on the increase in maximum lift coefficient ($\Delta C_{L_{max}}$) for the rectangular and the tapered wings is plotted in figure 12.

Some aerodynamic characteristics of the rectangular wing with flaps of different chord and at different locations and of the 5:1 tapered wing with tapered flaps at several locations are compared in table I.

It will be noted, for all wings and flaps tested, that the maximum lift coefficient increased as the flap hinge axis approached the trailing edge of the wing. (See also references 7 and 8.) The highest maximum lift coefficient with the full-span split flaps was obtained with a $0.20c_w$ flap with the hinge axis located at the $0.90c_w$ location. The values of maximum lift coefficient with flap deflected were slightly higher for the rectangular wing than for the 5:1 tapered wing at corresponding conditions. The $0.10c_w$ flap deflected at 75° gave much lower values of $\Delta C_{L_{max}}$ than those obtained with the $0.20c_w$ flap deflected

60° at similar locations on the rectangular wing. For both the wings tested, the values of the diving (negative) pitching-moment coefficients increased as the distance of the flap axis from the leading edge of the wing increased. These results are in general agreement with those of previous tests reported in references 7 and 8.

Comparison of Partial-Span Flaps with Full-Span Flaps at Various Locations

Previous tests of conventional partial-span split flaps (references 4 and 9) indicated that a $0.20c_w$ by 0.70b flap deflected 60° might be expected to give an increase in maximum lift coefficient of about 0.76 over the plain rectangular wing. The present tests of an N.A.C.A. 23012 rectangular wing show that a $0.20c_w$ full-span split flap deflected 60° with a fixed hinge axis at the $0.70c_w$ location gave an increase in maximum lift coefficient of 0.826 over that obtained with the flap neutral. If the hinge axis of the full-span split flap was moved from the $0.70c_w$ to the $0.90c_w$ location when the flap was deflected, the increase in maximum lift coefficient was 1.07. For the tapered wing, it was found necessary to move the $0.20c_w$ full-span flap back to at least the $0.75c_w$ location before the lift increments due to it exceeded those of a tapered partial-span flap (0.70b). The lift increments obtainable with full-span split flaps over those of conventional partial-span flaps on tapered wings also are considerably smaller than those indicated for rectangular wings. From the foregoing comparisons, together with the aerodynamic characteristics of wings with full-span flaps given in table I, it appears reasonable to expect a greater increase in maximum lift coefficient with a $0.20c_w$ full-span split flap than that obtained with the conventional partial-span split flap for full-span flap locations of $0.75c_w$ or more from the leading edge of the wing.

Aileron Characteristics, Rectangular wing

Rolling-, yawing-, and hinge-moment coefficients due to the $0.15c_w$ by 0.60 b/2 aileron on the rectangular wing for several angles of attack are given in figure 13(a) with flap neutral, 13(b) with $0.20c_w$ flap deflected 60° at the $0.65c_w$ location, and in 13(c) with the $0.20c_w$ flap deflected 60° at the 0.85c_w location. With the flap neutral (fig. 13(a)) an interesting point is the hump in the rolling-moment curves for aileron deflections of about 15° with the partial-span aileron. This effect may be a characteristic of the particular aileron and wing-section combination inasmuch as it has not been observed in tests of other arrangements. Comparison of the three sets of curves shows the effect on aileron control of the full-span flap when deflected to be a decrease in the slope of the rolling-moment-coefficient curve and a decrease in the adverse yaw. The rolling-moment coefficients for downward deflections of the aileron were also decreased when the flap was deflected. When the flap hinge axis with flap deflected was at the same wing-chord location as the aileron axis, the values of the rolling-moment coefficients for large up-aileron deflections were practically the same as when the flap was neutral. With these flap arrangements on the rectangular wing, the maximum rolling-moment coefficients occurred at 20° aileron deflection. For deflections of the aileron greater than 20° down, the rolling-moment coefficients rapidly decrease.

Figures 14(a), 14(b), and 14(c) give the rolling-, the yawing-, and the hinge-moment coefficients for the 0.10c_w by 1.00 b/2 aileron on the rectangular wing with the 0.20c_w flap neutral, deflected 60° at the 0.70c_w location, and deflected 60° at the 0.90c_w location. The same general results were obtained with the 0.15c_w by 0.60 b/2 aileron and the same flap, with the exception that the maximum rolling-moment coefficients due to the 0.10c_w by 1.00 b/2 aileron were slightly higher.

The rolling-, the yawing-, and the hinge-moment coefficients due to the 0.10c_w by 1.00 b/2 aileron on the rectangular wing with the 0.10c_w split flap deflected 75° at the 0.80c_w and 0.90c_w locations are plotted in figure 15. The aileron characteristics are similar to those obtained with the other combinations on the rectangular wing.

Aileron Characteristics, Tapered Wing

Figure 16 gives the rolling-, the yawing-, and the hinge-moment coefficients of the 0.15c_w by 0.60 b/2 tapered aileron on the 5:1 tapered wing with the 0.20c_w tapered full-span split flap neutral and deflected 60° at the 0.65c_w and 0.85c_w locations. The characteristics of the tapered aileron on the tapered wing with the full-span flap are of the same general nature as those of the various combinations of the ailerons and flaps tested on the rectangular wing. The rolling-moment coefficients due to the tapered aileron on the tapered wing are, in general, somewhat less than those obtained with the $0.15c_w$ by 0.60 b/2 aileron and the $0.20c_w$ flap on the rectangular wing under corresponding conditions. Owing to the smaller damping in roll of the tapered wing, the ailerons on this wing are, however, probably as effective as those on the rectangular wing.

CONCLUSIONS

1. A $0.20c_w$ full-span split flap located at approximately the $0.75c_w$ point gave higher lift coefficients than had previously been obtained with a conventional $0.20c_w$ partial-span split flap of a length to permit satisfactory control with plain ailerons.

2. The diving pitching-moment coefficients of the wing and the flap increased as the distance of the flap from the leading edge of the wing increased.

3. The slope of the curves of rolling-moment coefficient was decreased when full-span split flaps located ahead of plain ailerons were deflected.

4. When a full-span split flap was deflected at the same axis location as the aileron, the value of the rolling-moment coefficient for the maximum upward deflection of the aileron tested was about the same as when the flap was neutral; the maximum rolling-moment coefficient was less for down-aileron deflections than for flap neutral; and the adverse yawing-moment coefficients were less than for flap neutral.

5. The most promising arrangement of full-span split flap and plain aileron combination tested for both high lift and lateral control was the rectangular wing with $0.20c_w$ flap deflected 60° at $0.90c_w$ location and the $0.10c_w$ by 1.00 b/2 aileron.

6. The flap and aileron on the tapered wing gave somewhat lower lift and lower rolling-moment coefficients than the corresponding flap and aileron on the rectangular wing.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 26, 1938

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TABLE I

Comparison of Rectangular and Tapered N.A.C.A. 23012
Wings with Full-Span Split Flaps

Flap chord (percent c_w)	Flap location (percent c_w)	$C_{L_{max}}$	$\Delta C_{L_{max}}$	$\frac{C_{L_{max}}}{C_{D_{min}}}$	L/D at $C_{L_{max}}$
Rectangular wing					
No flap	-	1.091	-	128.4	12.1
20	15	.935	-0.156	110.0	5.36
	50	1.632	.541	192.0	5.13
	65	1.836	.745	216.0	4.96
	70	1.917	.826	225.5	4.98
	85	2.115	1.024	248.8	4.99
	90	2.161	1.070	254.2	5.16
10	80	1.774	.683	208.7	6.14
	90	1.923	.832	226.2	6.08
Tapered wing					
No flap	-	1.112	-	152.3	9.75
20	65	1.719	0.607	235.5	5.18
	85	1.996	.884	273.4	5.58

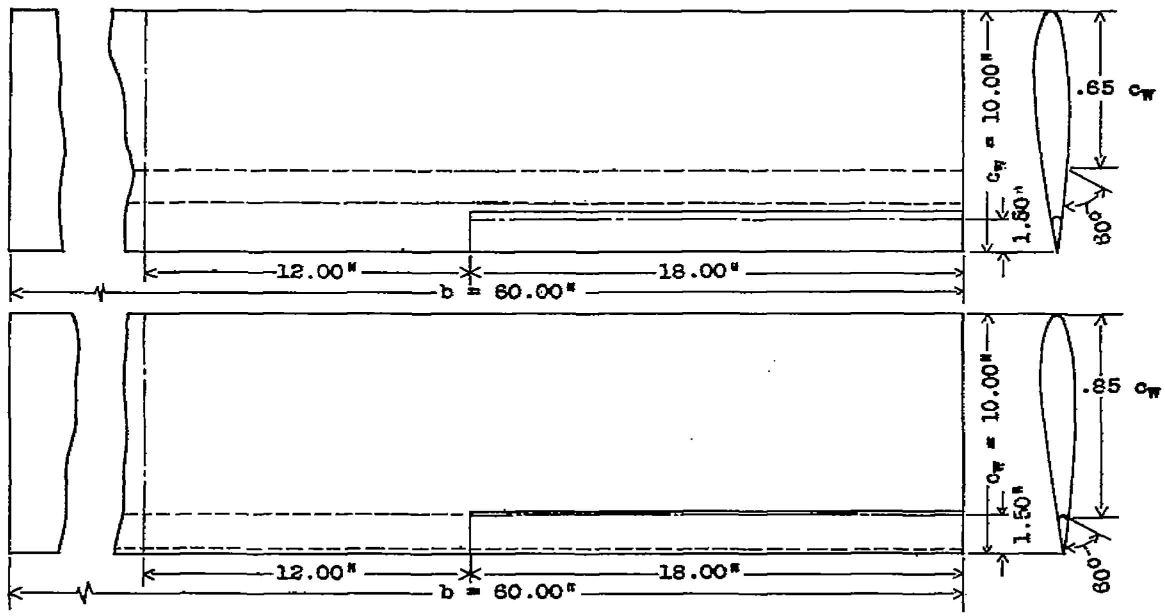


Figure 1. - The rectangular N.A.C.A. 23012 wing with 0.15 c_w by 0.60 b/2 plain ailerons and a full-span 0.20 c_w split flap at 0.65 c_w and 0.85 c_w .

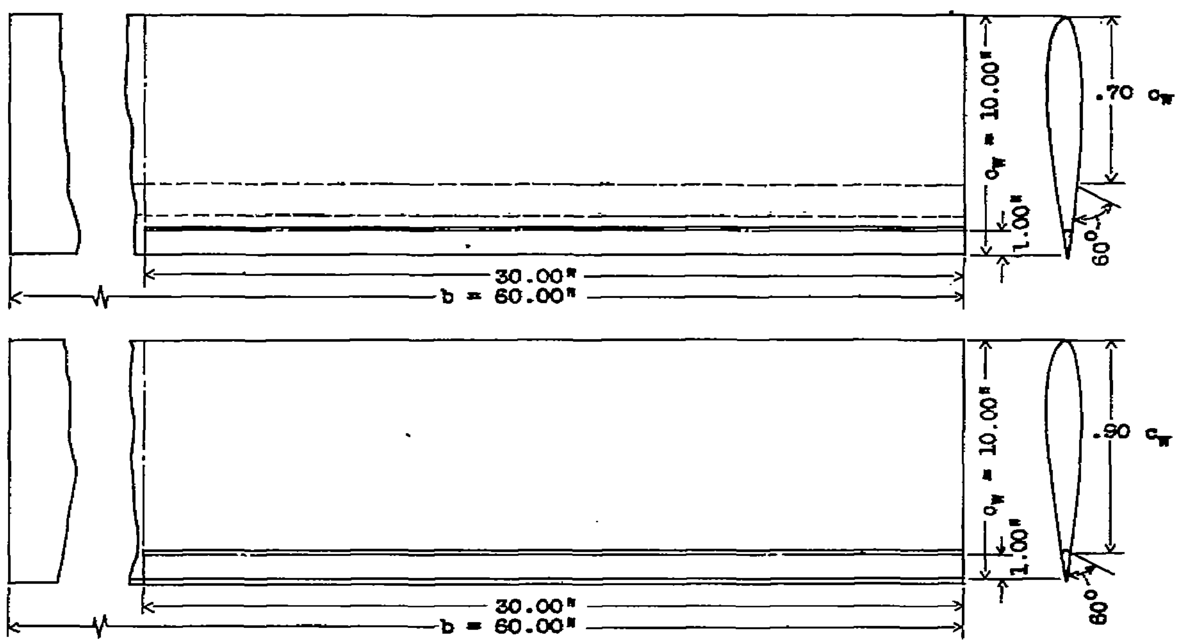


Figure 2. - The rectangular N.A.C.A. 23012 wing with 0.10 c_w by 1.00 b/2 plain ailerons and a full-span 0.20 c_w split flap at 0.70 c_w and 0.90 c_w .

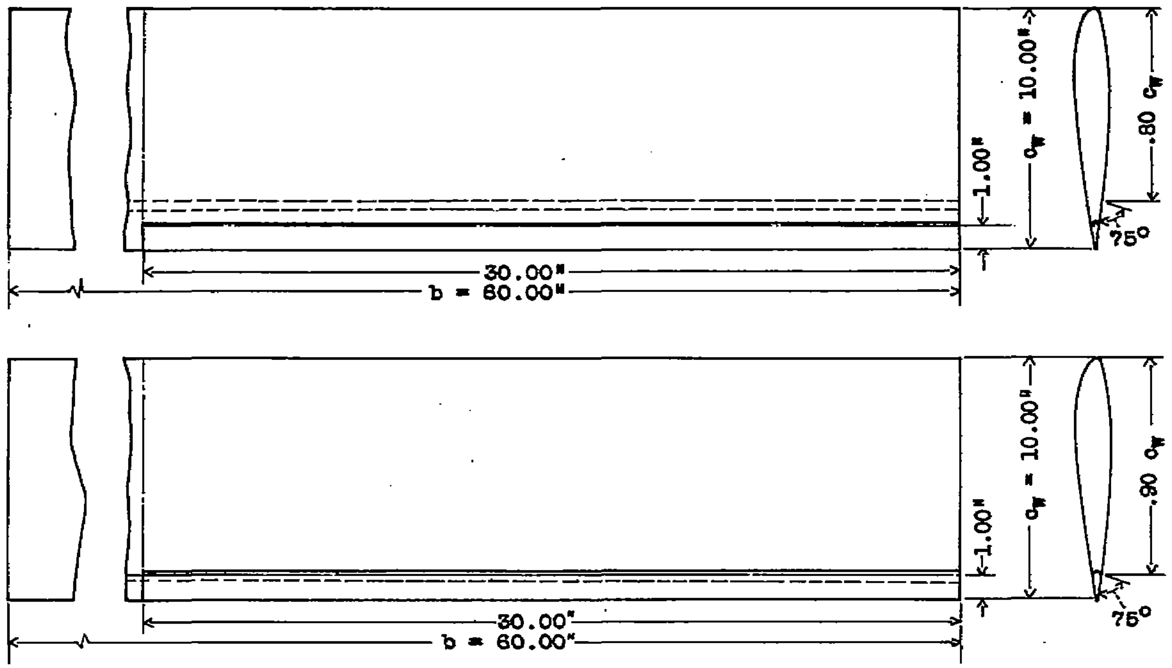


Figure 3. - The rectangular N.A.C.A. 23012 wing with 0.10 c_w by 1.00 b/2 plain ailerons and a full-span 0.10 c_w split flap at 0.80 c_w and 0.90 c_w .

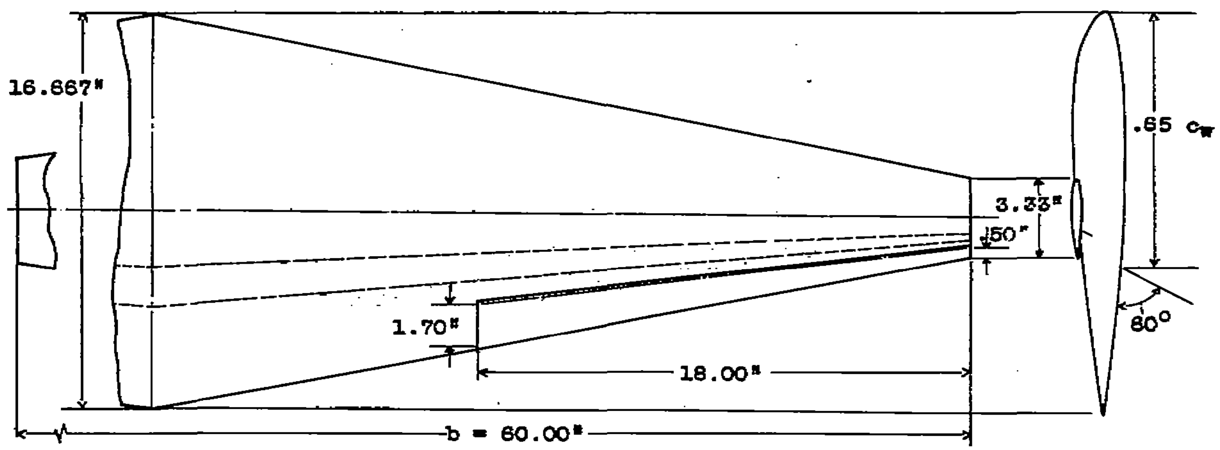


Figure 4. - The 5 : 1 tapered N.A.C.A. 23012 wing with 0.15 c_w by 0.60 b/2 tapered plain ailerons and a full-span 0.20 c_w tapered split flap at 0.65 c_w .

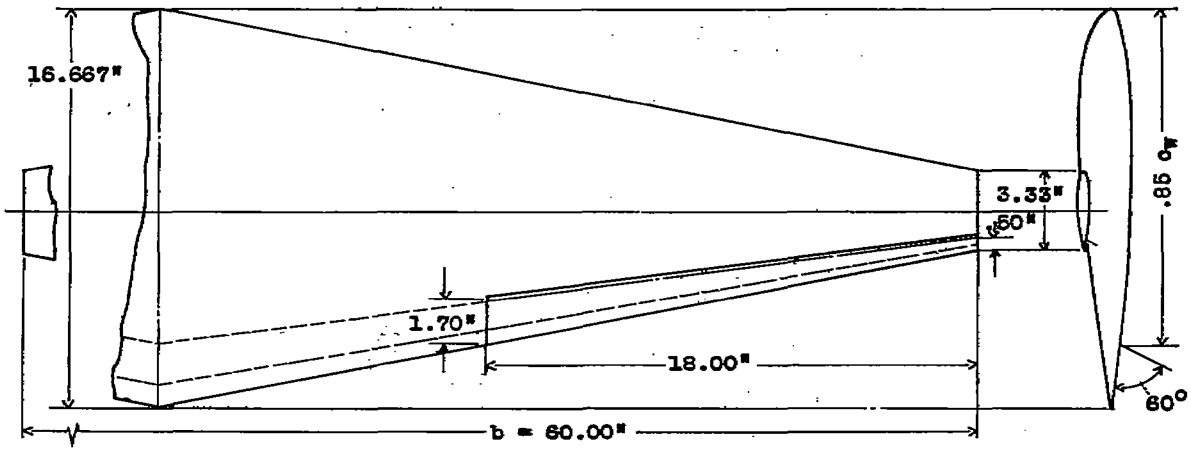


Figure 5. - The 5 : 1 tapered N.A.C.A. 23012 wing with 0.15 c_w by 0.60 b/2 tapered plain ailerons and full-span 0.20 c_w tapered split flap at 0.85 c_w .

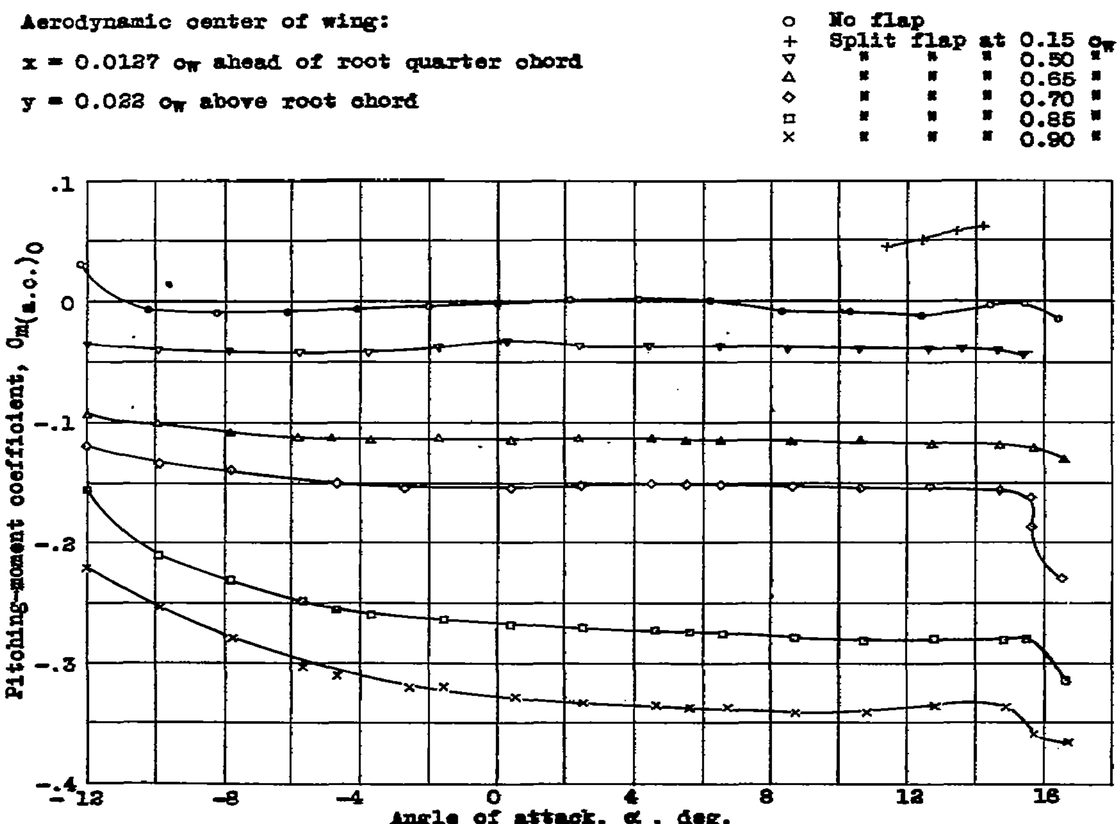


Figure 7. - Pitching-moment coefficient of rectangular wing with full-span 0.20 c_w split flap at various locations. Flap deflected 60° , aileron neutral.

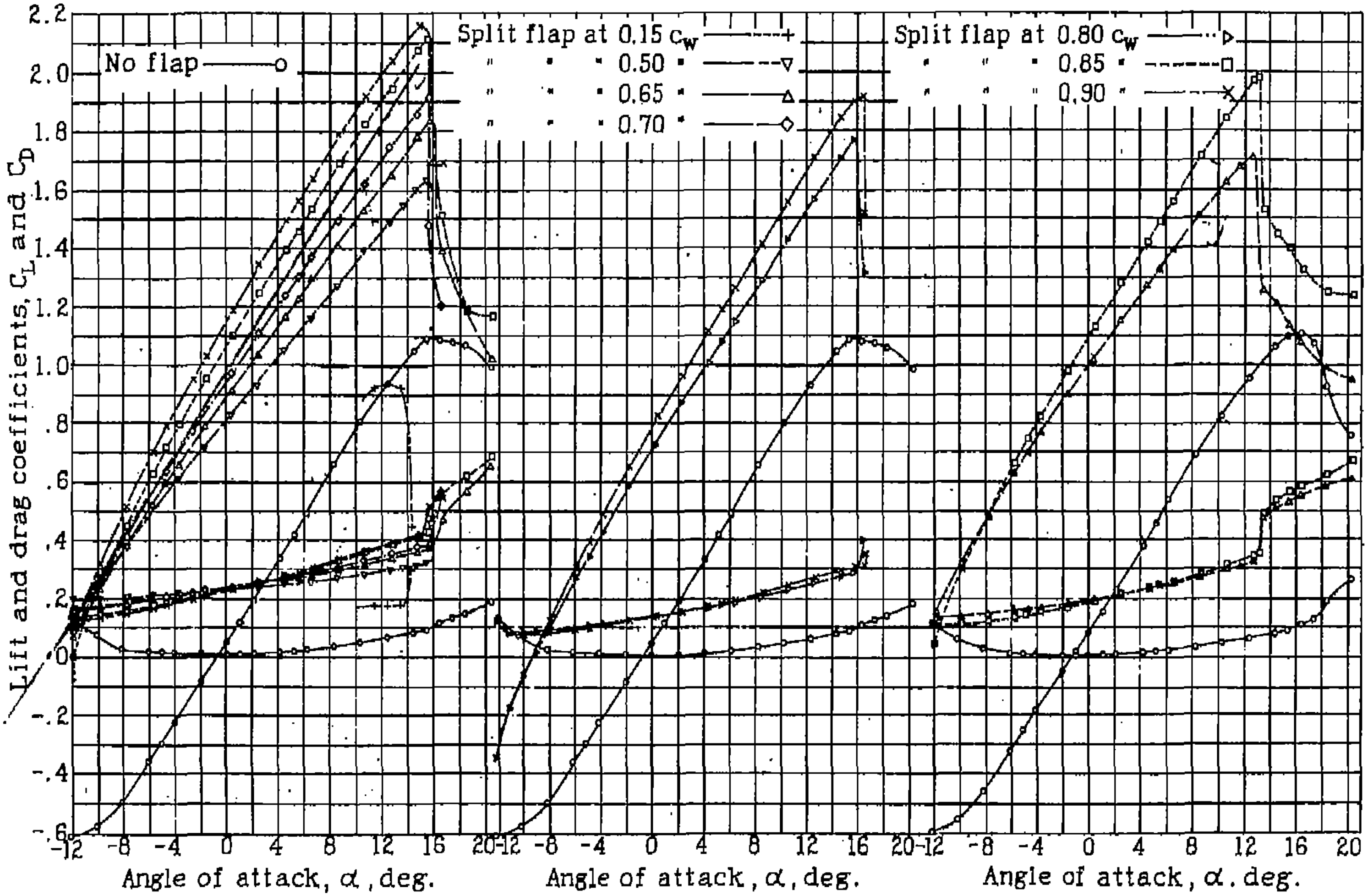


Figure 6.- Lift and drag coefficients of rectangular wing with full-span 0.20 c_w split flap at various locations. Flap deflected 60°, aileron neutral.

Figure 8.- Lift and drag coefficients of rectangular wing with full-span 0.10 c_w split flap at two locations. Flap deflected 75°, aileron neutral.

Figure 10.- Lift and drag coefficients of 5:1 tapered wing with full-span 0.20 c_w 5:1 tapered split flap at two locations. Flap deflected 60°, aileron neutral.

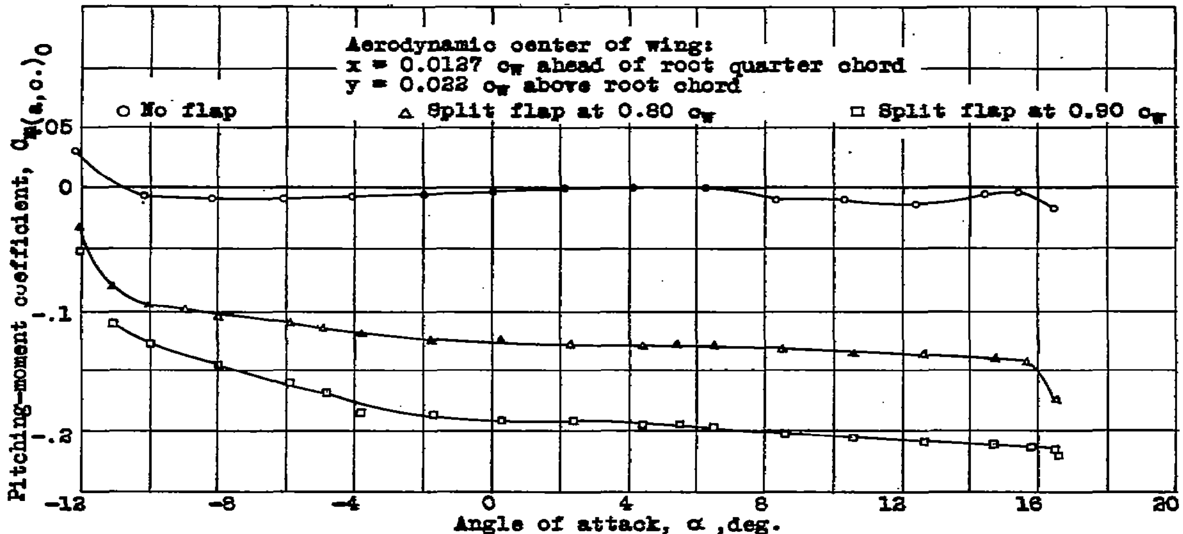


Figure 9. - Pitching-moment coefficient of rectangular wing with full-span 0.10 c_w split flap at two locations. Flap deflected 75° , ailerons neutral.

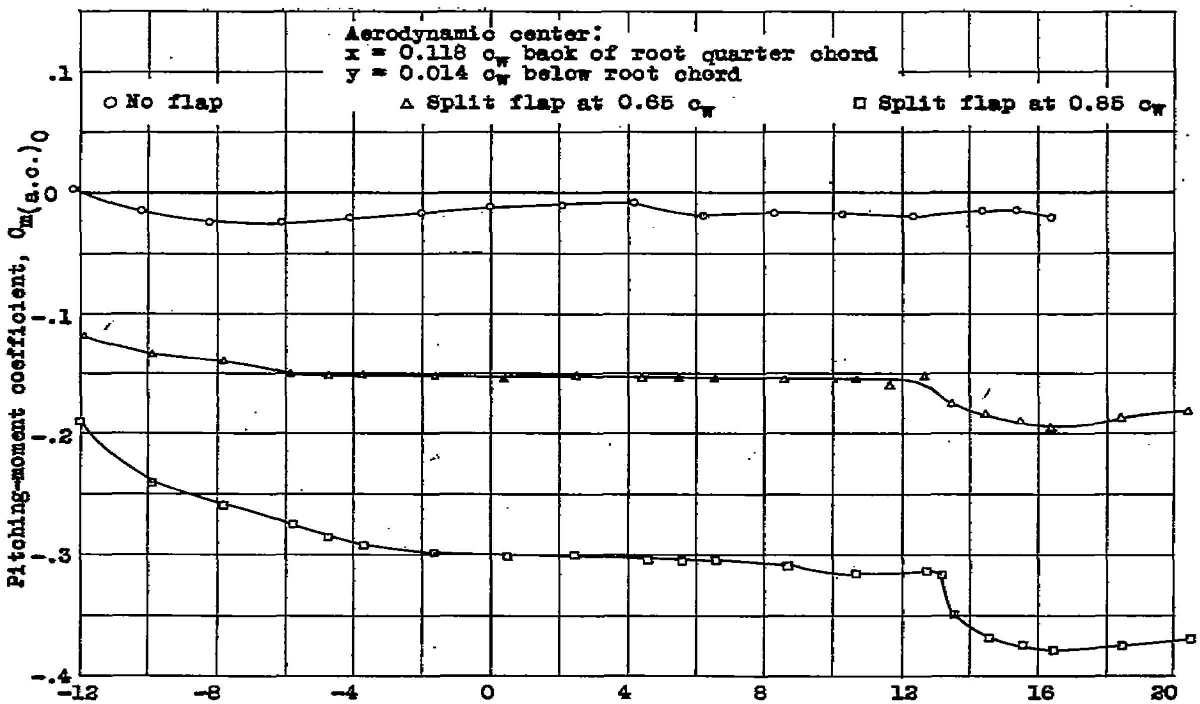


Figure 11. - Pitching-moment coefficient of 5:1 tapered wing with full-span 0.20 c_w 5:1 tapered split flap at two locations. Flap deflected 60° , aileron neutral.

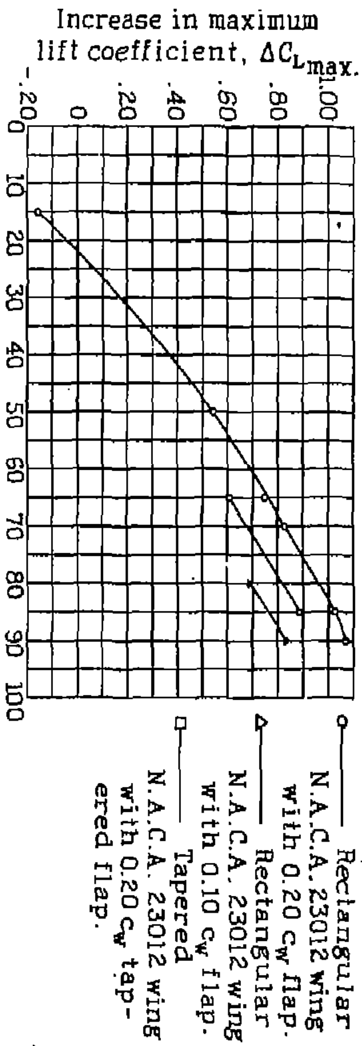


Fig. 12.- Effect of flap location on increment of maximum lift.

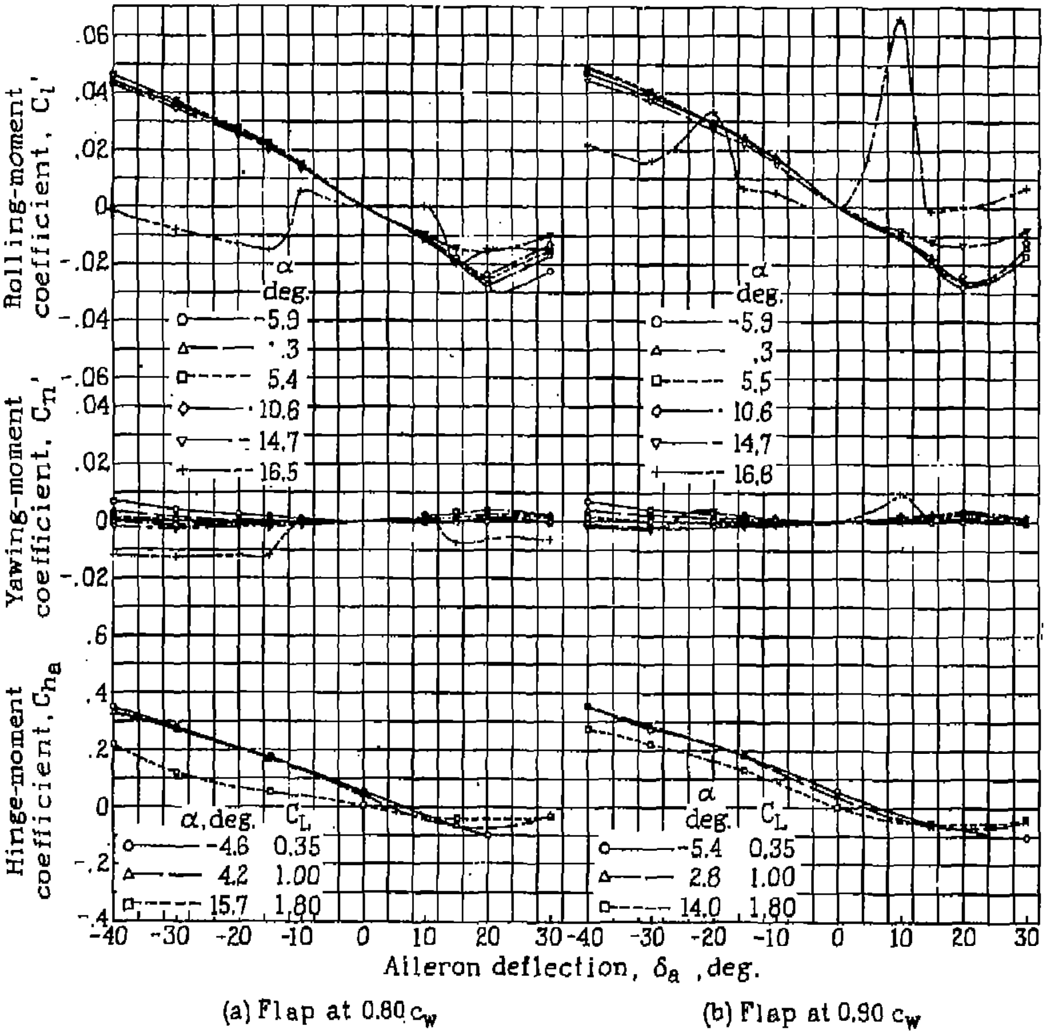
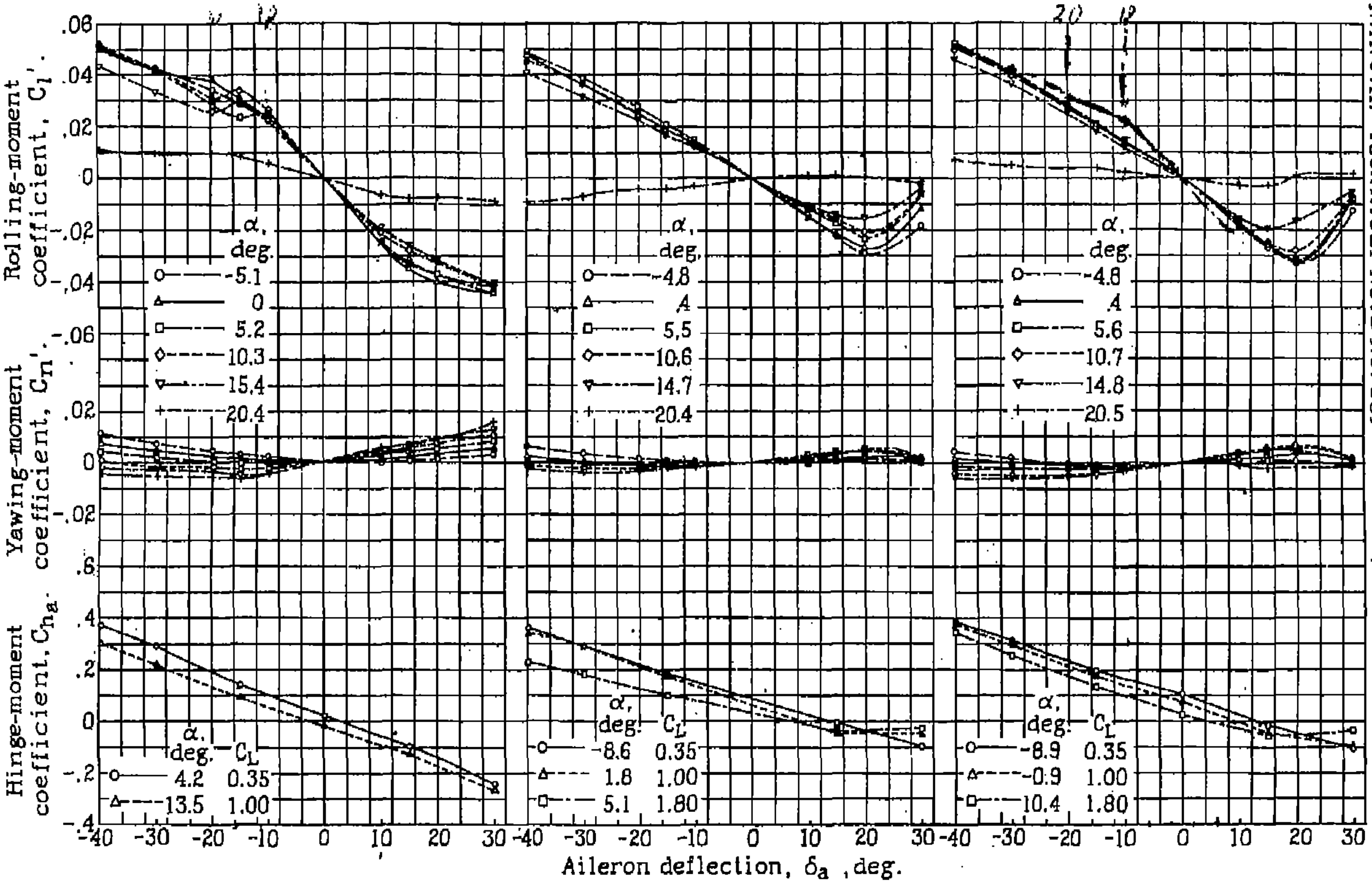


Figure 15.- Rolling-, yawing-, and hinge-moment coefficients of 0.10 c_w by 1.00 b/2 plain aileron on rectangular wing with full-span 0.10 c_w split flap deflected 75° at two locations.



(a) Flap neutral (b) Flap at 0.65 c_w (c) Flap at 0.85 c_w

Figure 13.- Rolling-, yawing-, and hinge-moment coefficients of 0.15 c_w by 0.60 b/2 plain aileron on rectangular wing with full-span 0.20 c_w split flap deflected 60° at two locations.

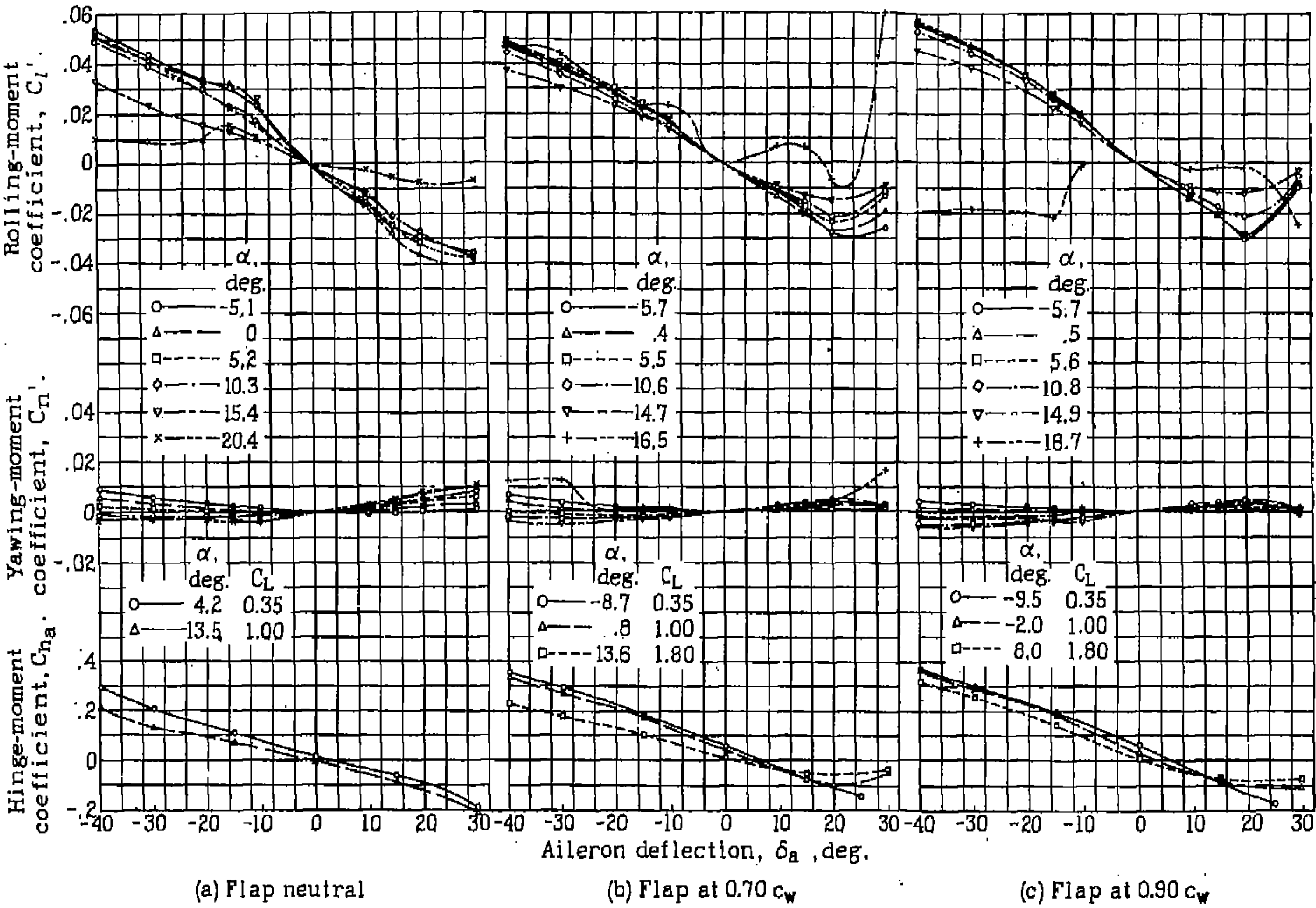


Figure 14.- Rolling-, yawing-, and hinge-moment coefficients of 0.10 c_w by 1.00 b/2 plain aileron on rectangular wing with full-span 0.20 c_w split flap deflected 60° at two locations.

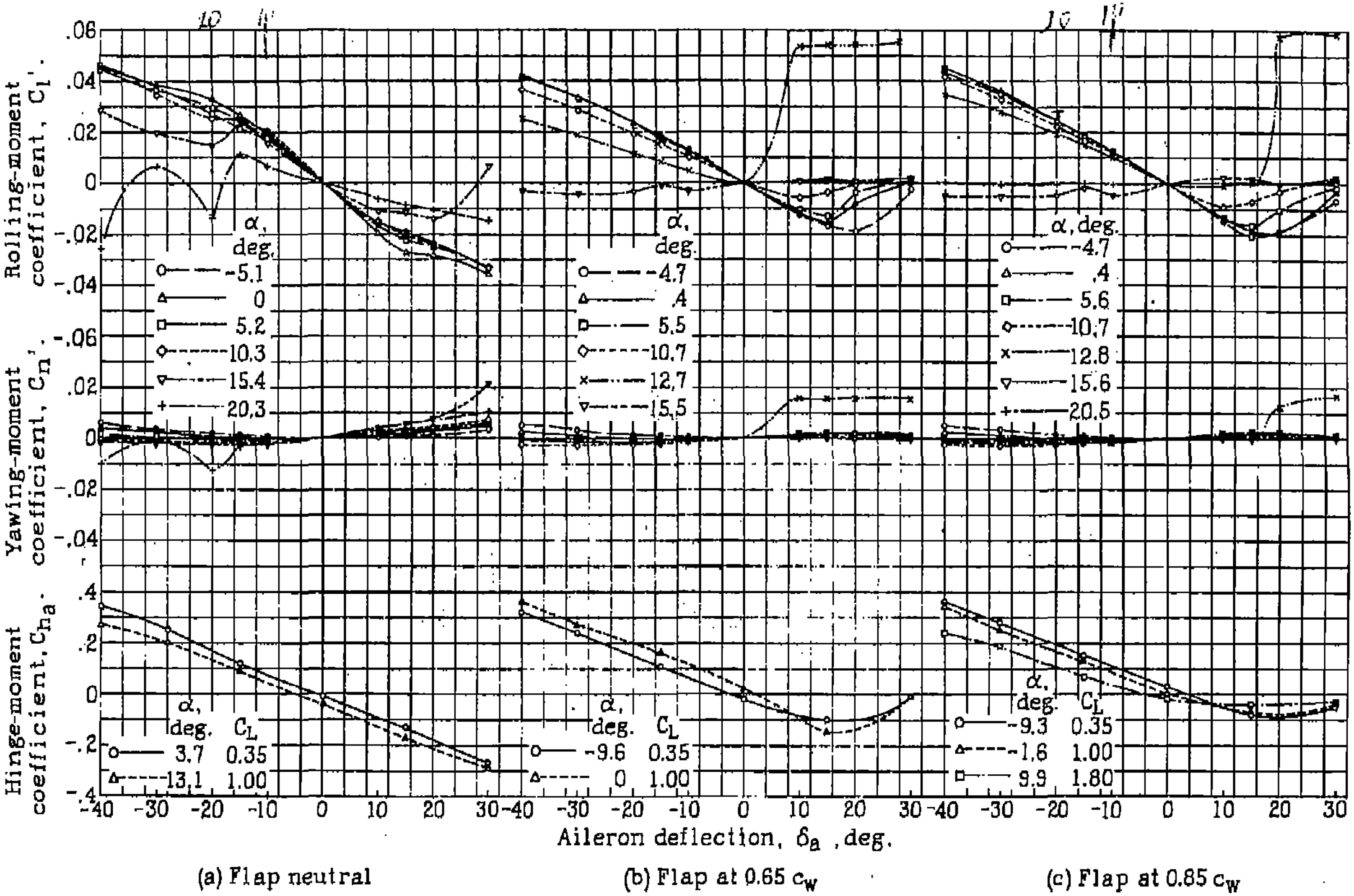


Figure 16.- Rolling-, yawing-, and hinge-moment coefficients of 0.15 c_w by 0.60 b/2 5:1 tapered plain aileron on 5:1 tapered wing with full-span 0.20 c_w 5:1 tapered split flap deflected 60° at two locations.